CORRESPONDENCE

Comments on "Accuracy of Atlantic Tropical Cyclone Forecasts"

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In a recent article Tracy [1] evaluated the accuracy of tropical cyclone forecasts. His comments on the bias of various forecast techniques needs further clarification. He discussed the bias with reference to north and south; then, instead of east and west, he used fast and slow. This description presumes only westward motion of tropical storms. In his figures 3 through 21 he used a large dot to represent the center of the observed positions and a cross to represent the forecast position. The displacement of the dot from the cross in an east or west direction is inadequate to determine if the forecast technique was too slow or too fast. If the description is correct for storms moving westward it should be just opposite for storms moving eastward. For storms moving northward or southward the terms fast and slow would be identical to north and south errors.

At least some of the probability ellipses, figures 3 through 21, used to depict the distribution of the observed about the forecast positions are improperly oriented. The discrepancy can be discerned by visual inspection where the data are ample and the ellipses markedly elongated along the major axis. It appears that the ellipses have the proper dimensions but should be rotated 90°.

REFERENCE

1. J. D. Tracy, "Accuracy of Atlantic Tropical Cyclone Forecasts," *Monthly Weather Review*, vol. 94, No. 6, June 1966, pp. 407–418.

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Comments on "Accuracy of Atlantic Tropical Cyclone Forecasts"

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I have read with interest Tracy's [1] evaluation of the various hurricane forecasting procedures. The article gives much worthwhile information on the accuracy of current forecasting methods. However, I have some questions concerning the correctness of figures 3 through 21.

Equations (1) and (2) in the paper define the shapes of the probability ellipses. Equation (3) then defines the orientation of these ellipses, and it is this orientation which is in question. The ellipses represent probability density values and should fit the plotted data in the figures in question. A casual inspection of the figures indicates that the density of the plotted data is not uniform near the outer ellipses. Sufficient detail is not given to evaluate the correctness of the data presented. If the data given in the article are assumed correct, the error appears to be in the interpretation of the rotation angle.

In the conventional x-y coordinate system (x positive to the east, y positive to the north), the positive rotation is taken in the counterclockwise direction. That is, a positive angle requires a rotation from the positive x-direction toward the positive y-direction or counterclockwise. In the coordinate system apparently used in the study, namely, the latitude and longitude system with longitude increasing in a positive sense toward the west, a positive rotation now requires a rotation from the positive longitude direction (west) into the positive latitude direction (north) or a *clockwise* rotation. Thus, in Tracy's figures 3 through 21, the major axes of the ellipses should be rotated in all cases in the opposite direction the amount given by the value of the rotation angle.

That the opposite rotation would bring the density ellipses into better agreement with the plotted data can be seen, for example, by examining Tracy's figure 16. Here the rotation angle of $-14.6°$ would require an orientation of the major axis of the ellipse in an essentially east-northeast to west-southwest direction (a rotation of 29.2° in a counterclockwise direction from that shown in the figure) giving a better fit to the data. (Note added March 8, 1967: In Mr. Tracy's reply which follows, he gives a rotation angle of $-75.4°$ for the revised orientation for figure 16. I would like to point out that this gives *exactly* the same orientation I have suggested above.)

REFERENCE

1. J. D. Tracy, "Accuracy of Atlantic Tropical Cyclone Forecasts," *Monthly Weather Review*, vol. 94, No. 6, June 1966, pp.407–418.

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Reply

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I thank Mr. Hoover and Mr. Jorgensen for their interest in my paper [1]. Soon after its publication, they and other readers called my attention to inconsistencies between the probability ellipses and the *plotted* data in figures 3–21, pages 412–417. The ellipses were inadvertently plotted incorrectly in a conventional x-y co-

ordinate system with x positive to the east, y positive to the north; but the ellipses were computed and should have been plotted (as are the data points) in an x-y coordinate system with x positive southward (positive latitude error) and y positive eastward (positive longitude error). The latter system was chosen as the more natural one for geographically orienting the vector errors, whose components were determined by subtracting the *observed* latitude (longitude) from the *forecast* latitude (longitude).

It has been determined that the variance of the latitude components, σ^2_{lat}, and the variance of the longitude components σ^2_{long}, of the vector errors were incorrectly related to the coordinate axis from which the angle ϕ was measured. Consequently, there can be no 90° rotation of the ellipses, as suggested by Mr. Hoover, to correct for this improper relationship.

All the angles have been recalculated and will be presented in a later section of this reply. When the ellipses are plotted with the correct angle, ϕ, the correspondence with the plotted data is much better. Except for those ellipses that were derived from a data sample which has been changed slightly after the discovery of a few data cards that were incorrectly labeled, other features (lengths of major and minor axes, positions of centers, etc.) of the ellipses are not affected. Also, for those cases in which the data sample was slightly changed, the resulting effect on the dimensions of the probability ellipses is almost undetectable. However, the data in table 10 on page 412 in the paper will be changed considerably.

It should be noted that the above corrections are not the same as the change suggested by Mr. Jorgensen since he mistakenly assumed that I had used a coordinate system with positive x and y in the direction of increasing west longitude and increasing north latitude, respectively.

To reply to Mr. Hoover's first paragraph, I must first change the first paragraph on page 416 of my paper to read as follows:

"Forecasts made while storms were in area C by the T–59 system yielded 'on the average' forecasts that were too far south and too slow, while those using the RHS system were primarily too fast, and those using the T–60 technique were too far south and too fast. Also in the area C, 'on the average' forecasts produced by the NWP method were too far south and too slow, those by the M–M method were primarily slightly slow, those by the PERS method were too slow, and in those by the WB method little bias was shown."

The above correction reflects appropriate changes for those forecasts in area C in which eastward movement of the tropical storms predominated over westward movement. A computer program was written for calculating these eastward versus westward displacements. Hence the revised statements above are quantitatively based. These quantitative evaluations apply to figures 7, 9, 12, 15, 18, and 21 in my paper.

It was experientially and subjectively believed that the vast majority of storms in areas A and B would have a predominantly westward to northwestward movement over most of their tracks. An inspection of the movement of storms for which forecast errors are displayed in figures other than those mentioned in the preceding paragraph reveals the following:

Number of Storms With Predominant Movement

Figure No.	*W-NNW*	*NNE-ENE*	*Not readily determinable*	*Total number of storms*
3	14	5	2	21
4	23	6	2	31
5	(*)	(*)	(*)	(*)
6	16	2	1	19
8	15	5	2	22
10	12	2	2	16
11	19	5	1	25
13	14	3	3	20
14	18	5	1	24
16	10	4	2	16
17	15	5	3	23
19	15	6	3	24
20	23	6	3	32

*Little bias indicated.

From this tabulation it can be determined that in no figure were less than 62 percent of the tropical storms for which vector errors are displayed moving with a predominant W–NNW movement.

From the above the writer believes that all the statements that have been made in the paper concerning those figures specified above are true.

In addition to the changes given above, the following corrections should be made in my paper:

(1) Page 408, table 2.—Change the data for the T–59 forecast technique for area C to read "Number of forecasts 126, Mean (n. mi.) 162, Standard deviation (n. mi.) 90, Median (n. mi.) 142, Lower quartile (n. mi.) No change, Upper quartile (n. mi.) 229, and Range (n. mi.) 6–398". Change the data for the PERS forecast technique for area A to read "Number of forecasts No change, Mean (n. mi.) 236, Standard Deviation (n. mi.) No change, Median (n. mi.) 176, Lower quartile (n. mi.) No change, Upper quartile (n. mi.) No change, and Range (n. mi.) No change".

(2) Page 409, table 7.—The column heading between "Standard Deviation" and "Lower Quartile" should be "Median", not "Mean".

(3) Page 411.—Change equations (1), (2), and (3) to read as follows:

$$a^2=\frac{2(1-\rho^2)\ln S}{\frac{1}{\sigma^2_{\text{lat}}}-\frac{\rho}{\sigma_{\text{long}}\sigma_{\text{lat}}}\tan\phi} \tag{1}$$

$$b^2=\frac{2(1-\rho^2)\ln S}{\frac{1}{\sigma^2_{\text{long}}}+\frac{\rho}{\sigma_{\text{long}}\sigma_{\text{lat}}}\tan\phi} \tag{2}$$

$$\phi=\frac{1}{2}\arctan\frac{2\rho\sigma_{\text{long}}\sigma_{\text{lat}}}{\sigma^2_{\text{lat}}-\sigma^2_{\text{long}}}. \tag{3}$$

(4) Page 411, left column, sixth line above the footnote.—Change the word "horizontal" to "vertical".

(5) Page 411, table 9.—The original table should be replaced with the accompanying revised table 9.

(6) Page 412, table 10.—The original table should be replaced with the accompanying revised table 10.

(7) Page 412, line 5 of caption to figure 3.—Change the word "horizontal" to "vertical".

(8) Using the table below, change the appropriate figure accordingly:

Page Number	*Figure Number*	$\overline{LAT.}$	$\overline{LONG.}$	θ
412	3	----------	----------	−55.3°
412	4	----------	----------	−44.5°
413	5	----------	----------	−33.5°
413	6	----------	----------	−49.5°
413	7	----------	----------	−18.9°
413	8	0.164	0.232	−56.5°
414	9	----------	----------	−23.2°
414	10	----------	----------	−30.3°
414	11	----------	----------	−43.3°
414	12	−0.341	−0.384	−39.7°
415	13	----------	----------	−58.9°
415	14	----------	----------	−52.9°
415	15	----------	----------	−30.5°
415	16	----------	----------	−75.4°
416	17	----------	----------	−62.5°
416	18	----------	----------	−49.0°
416	19	−1.028	0.940	+21.0°
417	20	----------	----------	−42.3°
417	21	----------	----------	−35.3°

TABLE 9 (revised).—*Summary of some of the relationships represented by the probability ellipses depicted in figures 3 through 21. 24-hr. forecast periods represented*

Name of technique	Fig. No.	Area	Average bias of the forecasts					Relative areas covered by ellipses for a particular technique			Probability contours (approximate)	
			Too far N	Too far S	Too fast	Too slow	None	Smallest	In between	Largest	Circular	Elliptical
WB	3	A	------	X	X	------	------	------	------	X	X	
	4	B	X	------	X	------	------	X	------	------	------	X
	5	C	------	------	------	------	X	------	X	------	------	X
M-M	6	B	X	------	------	X	------	X	------	------	------	X
	7	C	------	------	------	X	------	------	X	------	------	X
R-H-S	8	B	X	------	X	------	------	X	------	------	X	
	9	C	X	------	X	------	------	------	------	X	------	X
T-59	10	A	------	X	X	------	------	------	X	------	------	X
	11	B	------	------	X	------	------	X	------	------	------	X
	12	C	------	X	------	X	------	------	------	X	------	X
NWP	13	A	------	X	X	------	------	------	------	X	------	X
	14	B	------	------	X	------	------	X	------	------	------	X
	15	C	------	X	------	X	------	------	X	------	------	X
T-60	16	A	X	------	------	X	------	------	------	X	------	X
	17	B	X	------	------	X	------	X	------	------	------	X
	18	C	------	X	X	------	------	------	X	------	------	X
PERS	19	A	------	X	X	------	------	------	------	X	X	
	20	B	------	X	X	------	------	X	------	------	------	X
	21	C	------	X	------	X	------	------	X	------	------	X

TABLE 10 (revised).—*Percentage of forecasts contained within probability ellipses. Bivariate normal percentages (5 percent level)*

Name of technique	Figure No.	Area	20% probability ellipse		40% probability ellipse		60% probability ellipse		80% probability ellipse	
			Actual percentage	Maximum allowable absolute difference	Actual percentage	Maximum allowable absolute difference	Actual percentage	Maximum allowable absolute difference	Actual percentage	Maximum allowable absolute difference
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
WB	3	A	29	8.0	55	8.0	70	8.0	86	8.0
	4	B	27	6.7	49	6.7	68	6.7	81	6.7
	5	C	22	9.8	43	9.8	62	9.8	81	9.8
M-M	6	B	24	13.4	50	13.4	61	13.4	84	13.4
	7	C	21	22.1	50	22.1	66	22.1	79	22.1
R-H-S	8	B	23	12.9	43	12.9	68	12.9	86	12.9
	9	C	31	24.6	55	24.6	73	24.6	83	24.6
T-59	10	A	25	12.8	46	12.8	65	12.8	85	12.8
	11	B	24	8.5	43	8.5	61	8.5	81	8.5
	12	C	20	12.1	38	12.1	63	12.1	78	12.1
NWP	13	A	32	15.7	57	15.7	72	15.7	83	15.7
	14	B	23	12.1	48	12.1	69	12.1	81	12.1
	15	C	23	18.9	50	18.9	64	18.9	77	18.9
T-60	16	A	38	13.5	64	13.5	76	13.5	85	13.5
	17	B	27	8.9	51	8.9	64	8.9	82	8.9
	18	C	16	19.0	41	19.0	59	19.0	79	19.0
PERS	19	A	37	8.1	58	8.1	73	8.1	85	8.1
	20	B	28	6.7	51	6.7	71	6.7	83	6.7
	21	C	27	9.6	46	9.6	65	9.6	78	9.6

(9) Page 413, figure 7.—The value of the "$\overline{\text{Long.}}$" component should be preceded by a minus (−) sign. The center of the ellipses is, however, plotted correctly.

(10) Page 416, first paragraph.—Change as indicated elsewhere in this reply.

(11) Page 416, right-hand column, second line from the bottom.—After the word "figures" delete "3, 16, and 19" and replace with the following "3, 4, 13, 16, 17, 19, and 20."

(12) Page 417, left-hand column, second line from the top.—After the word "figures" delete "3, 16, and 19" and replace with the following "3, 4, 13, 16, 17, 19 and 20."

(13) Page 417, third paragraph in the section entitled "Acknowledgments".—Add the name "Harvey L. Bernstein" after the name "Robert L. Carrodus."

(14) Page 417, line 4 of the legend inserted on figure 21.—Change the word "horizontal" to "vertical."

REFERENCE

1. J. D. Tracy, "Accuracy of Atlantic Tropical Cyclone Forecasts," *Monthly Weather Review*, vol. 94, No. 6, June 1966, pp. 407–418.

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